

(19) World Intellectual Property Organization  
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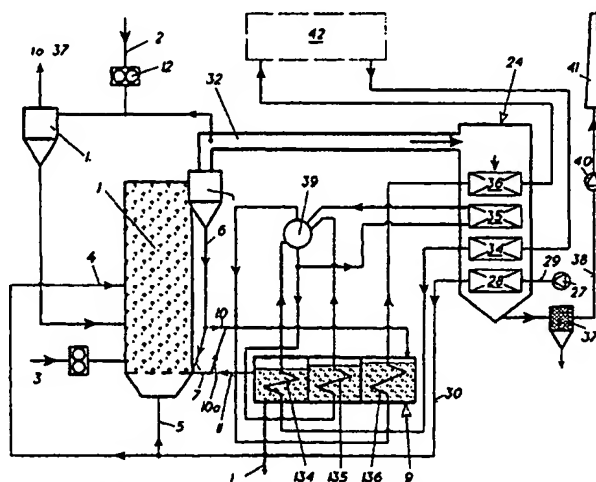
(43) International Publication Date  
4 October 2001 (04.10.2001)

PCT

(10) International Publication Number  
**WO 01/73343 A1**

- (51) International Patent Classification<sup>7</sup>: **F22B 31/00, C04B 2/00**
- (21) International Application Number: **PCT/IB01/00467**
- (22) International Filing Date: **9 March 2001 (09.03.2001)**
- (25) Filing Language: **English**
- (26) Publication Language: **English**
- (30) Priority Data:  
**00105999.7 27 March 2000 (27.03.2000) EP**
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- (81) Designated States (national): **AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.**
- (84) Designated States (regional): **ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).**
- Published:  
— with international search report  
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **METHOD OF PRODUCING STEAM AND AN ALTERNATE PRODUCT IN A POWER PLANT**



(57) Abstract: A process of producing steam and an alternate product in a power plant comprises feeding a reactant raw material (2) hydrocarbon (3) and an oxygen-containing gas (5) in a high temperature zone of a boiler (1), performing an endothermic reaction on the reactant in the boiler, discharging the product, producing steam in the boiler, further feeding the produced steam to a steam turbine island (42) comprising a steam turbine being drivingly connected to a generator. The power plant is operated during high demands of steam or electricity in a steam cycle, whereas during low demands of steam or electrical power the power plant is operated in a calcination mode maximizing the production of the alternate product with reduced steam production. The boiler is preferably a circulating fluidized bed boiler. At least one of the reactants is limestone and the alternate product can be lime or cement clinker.

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## **Method of producing steam and an alternate product in a power plant**

### **Field of the invention**

The invention relates to a process of producing steam and an alternate product in a power plant, comprising feeding a reactant raw material, hydrocarbon and an oxygen-containing gas in a high temperature zone of a boiler, performing an endothermic reaction on the reactant in the boiler, discharging the product, producing steam in the boiler, further feeding the produced steam to a steam turbine island comprising a steam turbine being drivingly connected to a generator.

### **Discussion of Background**

A method of producing cement clinker as alternate product and steam as described above in the „field of the invention“ is known from the article „Challenges of circulating fluid bed reactors in energy and raw material industries“ by Lothar Reh, published in DECHEMA Deutsche Gesellschaft für chemisches Apparatewesen, Chemische Technik und Biotechnologie e.V., Frankfurt am Main. This article is based on a lecture held on the 6th International Conference on Circulating Fluidized Beds, in Würzburg, Germany on August 22-27, 1999. This article describes trigeneration of cement, electricity and heat from high-ash coal using Circulating Fluidized Bed-Technology.

Limestone and high-ash coal are separately prepared and ground to below about 90 microns before feeding them into the boiler. These two basic raw materials are proportioned online. Limestone undergoes an endothermic reaction (is calcined) to lime in the boiler, while steam is simultaneously produced in the boiler. Sulfur is completely bound into the bed material, which has the chemical composition of clinker. The hot bed material is discharged directly into a small rotary kiln. This direct use of ash substituting the clay component in cement avoids disposal of ash completely.

The equipment size and fuel firing rate in the above case is determined by the total energy requirement for the combination of the steam production and the endothermic reaction of calcination and is larger than if steam production is performed alone. This known method also requires high performance cyclones in order to catch and recycle the pulverized limestone and/or lime and the grinding of the high-ash coal prior to its entry in the boiler. This is because the pulverized limestone is much finer than the typical recirculating bed material in a circulating fluidized bed boiler.

In CH 68980 a method for simultaneous production of cement clinker and electricity is described in which the calcined material is continuously fed from the calciner/boiler to the kiln. To alter the electricity production it is necessary to either increase the coal firing in the calciner which in turn increases the flue gas output for which the equipment according to CH 68980 would not be able to cater, or, alternatively, it is necessary to reduce the lime and hence cement production to increase the heat flow towards the steam production unit. Therefore, there is no flexibility to alter electricity production whilst keeping the cement production constant.

### Summary of the invention

Based on the fact that there are time periods in power plant operation where electricity price is low, the object of the invention is to provide a method of producing higher value-added products during these periods. A second object of the invention is to achieve cost-effective equipment utilization by changing operating conditions in time (temporal) with minimal changes to existing equipment to produce the alternate higher value-added products and not using larger pieces of equipment

This is achieved, according to the invention, in that the power plant is operated during high demands of steam or electricity in a steam cycle, whereas during low demands of steam or electrical power the power plant is operated in a mode maximizing the production of the alternate product by performing an endothermic reaction on the reactant with reduced steam production, the alternate product being stored after the endothermic reaction.

Said method comprises the steps of burning fuel, transferring heat to a medium, and expanding steam in a series of turbines which generates electricity during power mode, whereas during calcination mode a varying amount of reactants for endothermic reaction is fed to the high temperature zone of the plant, thus producing a high value product with the existing hardware.

The advantages of the invention are to be seen in that with the same equipment and with temporal variation of the operation at least two products like power and lime or cement clinker can be produced, i.e. one product that has time varying fluctuation of value and cannot be stored, and another product that can or cannot be stored and that has a stable value as a function of time.

If the boiler is a circulating fluidized bed boiler, wherein the gas and the solids out of the fluidized bed enter a cyclone, the solids being separated therein being returned to the bed, whereby part of those solids are first cooled down in a fluidized bed heat exchanger producing steam, whereas the gas and the fly ash escaping the cyclone are passed through at least one heat exchanger and through a filter, it is appropriate to design the cyclone system so as the lime-rich circulating material does not escape the cyclone system, and to discharge the calcined alternate product from at least one compartment of the multi-compartment fluidized bed heat exchanger. The size of the particles entering the cyclone are in the range of 200 microns and larger similar to traditional circulating fluidized beds and therefore specially designed cyclones are not necessary.

This advantage is to be seen in a significantly smaller number of cyclones leading to lower capital cost, because the cyclone system may have a larger cut size than the above mentioned prior art devices. For example in the approach of the above cited prior art, pulverized limestone smaller than 90 microns is used, which require a larger amount of smaller cyclones than traditional circulating fluidized beds for separation. The present cyclone system has a lower pressure drop, which leads to lower power consumption and lower operation cost. It also has a higher reliability due to the absence of fines in the material collected in the cyclone, which becomes easier to discharge. Another advantage is seen in the fact that there is no need to grind the fuel and the reactant feed. Lastly the nitric oxide emissions are lower.

If the boiler is a circulating fluidized bed boiler, wherein the gas and the solids out of the fluidized bed enter a cyclone, the solids separated therein being returned to the bed, whereas the gas and the fly ash escaping the cyclone are passed through at least one heat exchanger and through a filter, it is appropriate to size the reactant so as to be retained in the furnace of the boiler, to feed

at least part of the calcined alternate product to a fluidized bed heat exchanger with immersed tubes, in which it is cooled down while steam is produced and to discharge the calcined alternate product from at least one compartment of the multi-compartment heat exchanger. By sizing the reactant large, such that it is retained in the bed, the load and pressure drop across the cyclone is reduced resulting in lower power consumption.

In a suggested scenario to produce calcined raw meal for the cement production in a power plant, it is assumed that the power plant delivers power to the grid and produces a mixture of sulfated lime (degree of sulfating around less than 10%) and combustion residues like ash and a small amount of carbon. Thus if the reactant is limestone and the alternate product is lime, the advantages are to be seen in that, in a cement clinkering process, in avoiding calcination of the material fed to the preheater, a considerably reduction of the specific kiln heat consumption is performed. In fact if the raw meal is introduced in calcined form, a considerable increase in clinker production can be achieved while burning the same amount of the fuel in the kiln. Moreover, on the contrary to prior art arrangement of cement plants in which the hot clinker cooler air is one of the main sources of losses, in the proposed new method it is possible to use the hot air of the clinker cooler to a maximum extend. Thus the use of hot cooler air for preheating the precalcined material as well as the use of the kiln gases for steam production means another reduction of the specific kiln heat consumption. Moreover this air is free from  $\text{SO}_2$  thus avoiding or at least significantly reducing the risk of blockages in the preheating zone, as the sulphurous material is introduced directly at the kiln inlet at a temperature greater than 800 C. Furthermore the new method allows to significantly reduce the flue gas generated per kg of produced clinker and therefore the specific energy losses associated with the kiln flue gases are less.

The use of the calcined raw mix according to this method leads to an overall reduction of CO<sub>2</sub> and NO<sub>x</sub> emissions associated with the amount of clinker produced.

It is known that lime can re-carbonate ( $\text{CaO} + \text{CO}_2 \rightarrow \text{CaO}_3$ ) above the 540°C and below the 800° C that is the typical temperature range of the solids in the last cyclones of the pre-heater tower. The new method avoids this problem, as the preheating medium does not contain CO<sub>2</sub>.

The method is particularly interesting whether the cement plant and the power plant producing the calcined raw mix are located on the same site or not. The use of the combustion products like ash and carbon of the power process in the cement process avoids disposal of solids from the power plant.

If the reactants are limestone, clay, iron compounds and other additives constituting the composition of cement raw meal, the alternate product may be a lime-rich intermediate having the correct composition to produce cement clinker.

If the circulating fluidized bed is operated at a low excess air level, the carbon then contained in the fly ash escaped from the cyclone and separated in the filter and the carbon added via discharged fluidized bed material can be supplied to a (downstream) clinkering process as a fuel.

The advantage includes operating flexibility without loss of boiler efficiency, because a downstream process will burn the fuel completely. Because of low excess air, lower NO<sub>x</sub> and also higher production capacity are expected.

During power mode the injection of sulfur sorbent can be ceased or at least reduced. The advantages include the absence of any calcination duty during the power mode, which means a larger fraction of the fuel heat input can go towards steam/power production compared to standard steady state operation which requires continuous feeding of sorbent for sulfur capture and that has to

be calcined. Another advantage includes the very high Ca/S ratio during the power mode which allows the flexibility to operate the combustor at a wider range of operating conditions minimizing CO, hydrocarbon and NO<sub>x</sub> emission and high levels of carbon burnout and thermal efficiency while keeping very low SO<sub>2</sub> emission because of the high Ca/S ratio. The high Ca/S ratio also means that the sorbent material is much more reactive to SO<sub>2</sub> (very low CaSO<sub>4</sub> content) compared to standard CFB sorbent circulating at a utilization of around 40 to 50% (molar CaSO<sub>4</sub>/CaO is about 1)

The calcined material may be cooled before grinding. This allows reliable operation of the downstream grinding equipment and gives an opportunity for further steam production. Moreover the same equipment that was doing heat duty for steam production during power mode can be used to duty during calcination mode.

During the calcination mode, the circulating fluidized bed can be operated with oxygen-enriched air (O<sub>2</sub> > 21 volume %). The advantage is that the capacity of firing that can be done during the calcination mode to make more lime can be augmented.

### **Brief description of the invention**

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as they same becomes better understood by reference to the following detailed description when considered in connection with several exemplary embodiments schematically shown in the accompanying drawing.



- Fig. 1 illustrates the preparation of the calcined product in a power plant with a circulating fluidized bed steam generator;
- Fig. 2 illustrates a flow variant of the calcined product;
- Fig. 3 illustrates 3 diagrams with the cyclic operation in function of time;
- Fig. 4 illustrates a cement production plant;
- Fig. 5 illustrates a further cement production process;
- Fig. 6 illustrates a variant of the embodiment of Fig. 5.

Only the elements essential for understanding the invention are shown. Arrows illustrate the flow direction of the working media.

### **Description of the preferred embodiment**

Fig. 1 illustrates in a simplified block diagram the clinker making process and shows how the calcined raw meal, consisting essentially of lime and combustion residues like ash, carbon and desulfurization residues, is produced in the combustor of a power plant. The example is first described in the power generation mode.

Via air intake line 29 a fan 27 sucks ambient air in the system. This air is preheated in an air preheater 28. Via line 30 the air is fed to the combustor 1, in which it penetrates via a fluidizing air supply 5 and a secondary or overbed air supply 4.

Depending on the apparatus type, the air can be introduced into the combustor on different levels. In the example shown on the drawing, in which the reactor is an upright circulating fluidized-bed steam generator with a flow stream from bottom to top, the fluidizing air is introduced at the bottom through an air distributor. The secondary air is fed through one or more elevations of ports in the

lower combustor. The reactor is provided with three other inlets. One carbonaceous residue supplies line 7, one inlet 3 for the hydrocarbon which is coal in the present case and one inlet 2 for the raw cement meal.

Coal is introduced mechanically or pneumatically to the lower portion of the reactor combustor via supply 3. This coal can be either crushed or pulverized. Like the air, coal may be injected on different levels of the reactor. If the coal is in form of crushed material with a size of approximately 6-mm, it can be fed by gravity.

Combustion takes place throughout the combustor, which is filled by bed material. Flue gas and entrained solids leave the combustor and enter one or more solids separation devices, i.e. cyclones 8, where the solids are separated.

The flue gas and the fly ash exit the gas outlet of the solids separation device 8 via a flue gas line 32. These separated gases are further treated before disposal. They are first cooled down in the boiler backpass 24, thereby heating up and evaporating water and superheating the steam in heat exchanging surfaces integrated in the water/steam cycle of a steam turbine island 42.

Downstream the gases are further cooled in the air preheater 28. Downstream the gas cooler a solids filter 37 is provided in the line 38 to remove from the gas all the remaining solids. This filter 37 could be a fabric filter or an electrostatic precipitator. A fan 40 is installed in the gas line exiting the filter, preferably on the clean side of the filter 37. Its purpose is to control the pressure in the system close to atmospheric conditions. The cleaned gas leaves the system via the stack 41. The solids separated in the filter 37 can be fed to an appropriate location in a downstream cement manufacturing process.

The solids separated in the cyclone 8 are recycled to the combustor via line 6. In this example the major amount of circulated material is directly returned to

the fluidizing bed via inlet 6. Some solid is diverted via dotted line 10 to an external fluidized-bed heat exchanger (FBHE) 9 and then added to the portion in line 7 via dotted line 11.

The bed temperature in the combustor 1 is essentially uniform and is maintained at an optimum level for sulfur capture and combustion efficiency by heat absorption in the system. Steam duty is performed partly in the heat exchanging surfaces in the backpass 24 of the boiler and partly in the fluidized-bed heat exchanger 9, that is of the multi-compartment type and is containing immersed tube bundles. An economizer 34 in the backpass is fed with feedwater from the turbine island 42 and is serially connected to an economizer 134 in the FBHE. The preheated water is fed to a steam drum 39. Feedwater is then fed in parallel streams to an evaporator 35 in the backpass and to an evaporator 135 in the FBHE. The produced steam is collected in the drum 39. Superheating of the steam is performed by further heat removal from the hot solids absorption in a superheater 136 in the FBHE and in the serially connected superheater 36 of the backpass.

The flow rate of the solids through the FBHE 9 via dotted line 10 can be used to control the steam temperature. The produced superheated steam is fed to the turbine island 42 comprising at least one steam turbine driving a generator producing electrical power.

Sulfur compounds in the fuel or in the cement raw materials are mainly released in the CFB reactor 1 as  $\text{SO}_2$ . In traditional CFB steam production units, the amount of limestone needs to be minimized - Ca/S molar ratio typically around 2 - to minimize operating costs. In the present method, Ca/S molar ratios much greater are used in the CFB to improve the sulfur capture from flue gas exiting the system via stack 41. No attendant increase in operating costs

results since a very high amount of calcium relative to sulfur is inherent in the downstream cement clinker making process.

The described power mode may be illustrated in more detail with reference to a numerical example: it goes without saying that the calculated values given in connection with the said numerical values are examples only. With regard to the dimensioning of the involved apparatus, absolute values are in any case not meaningful enough on account of their dependence on numerous parameters.

Steam duty distribution between the backpass 24 and the FBHE is supposed to be about 35/100. With 5.6 kg/s coal burned in the CFB, the heat extracted from the backpass is about 37 MW<sub>th</sub> and from the FBHE about 108 MW<sub>th</sub>.

Air in the amount of 61 kg/s is introduced in the preheater 28 at a temperature of 42°C. It is heated up to 356°C by 70 kg/s of flue gas, that is taken from the outlet of the backpass 24 and enters the preheater at a temperature of 385°C. The air is fed to the CFB 1 as fluidizing and secondary air, while the flue gas is further treated at a temperature of 150°C.

The temperature in the furnace and in the freeboard of the CFB is at about 850°C. The solids/gas ratio at the outlet of the freeboard is supposed to be 12, whereby the flue gas amount is the above-mentioned 70 kg/s. The major amount of the 830 kg/s of solids separated (a cyclone efficiency of 99% is assumed) in cyclone 8, i.e. 460 kg/s is returned via line 7 directly to the bed, while the remaining portion, i.e. 380 kg/s half is fed via dotted line 10 to the FBHE, cooled therein and returned to the bed at a temperature of 356°C.

This power generation mode is performed during a time period of 12 hours, i.e. the day period where the price of power is high. A maximum energy that can be

transferred is directly used for steam generation. It is to be noticed that during this period, no sulfur sorbent has been introduced in the system.

According to the invention, during low demands of electrical power, i.e. at night periods, the power plant is now operated in a calcination mode maximizing the production of the alternate product with reduced steam production. The CFB is used for a coproduction of steam and calcined raw mix for the cement production, in which coproduction the ashes of the power production are used to replace part of the cement raw mix in the cement production. Indeed coal ashes are similar in composition to calcined clays. Moreover all of the coal residues are converted into cement; the sulfur is absorbed by clinker component CaO. The steam production during the calcination mode is supposed to be 30% of that during the power generation mode.

Via line 2 and a crusher 12 the reactant that is limestone or raw cement mix in the present case is provided in the reactor 1. In a first embodiment the limestone is sized so as to be retained in the furnace of the boiler. Before injecting the raw material in the boiler, it is preheated in a solids heater that might be a cyclone by hot flue gases extracted from the gas and fly ash line 32. The preheated material then undergoes an endothermic reaction to lime in the boiler.

At temperatures above about 800°C, limestone  $\text{CaCO}_3$  is calcined into lime CaO. A small portion of the CaO combines with  $\text{SO}_2$  released from coal combustion and oxygen to form gypsum  $\text{CaSO}_4$ .  $\text{SO}_2$  can be disposed by standard wet or dry scrubbing methods using limestone.

In this embodiment, during the calcination mode the whole amount of solids separated in cyclone 8 are recirculated to the bed. Draining off solids again controls solids inventory in the combustor. The amount of alternate products to be produced is discharged from the bottom of the bed and fed via line 10a to

the FBHE, in which it is cooled down in traversing the multiple compartments, thereby producing some steam and is finally drawn off via line 14.

The hot solids drained of the FBHE may then be introduced in a grinder (not shown) in which they are ground to an extent that 90% are below 90  $\mu\text{m}$ . They can be mixed with additives introduced in the grinder. These corrective additives are used, if any essential chemical compound needed in the mixture of coal ash and limestone like iron oxide or silica content are not present in the required amount. The calcined raw mix of the correct size and composition for cement clinker making is then forwarded to a cement plant. Ashes discharged during power mode can complete this mix.

The described calcination mode is now illustrated in more detail with reference to a numerical example:

With 5.3 kg/s coal burned in the CFB and 44 kg/s of limestone calcined to lime, the heat extracted from the backpass is about 38  $\text{MW}_{\text{th}}$  and from the FBHE about 10  $\text{MW}_{\text{th}}$ , and the amount of drained off alternate product is about 24 kg/s.

Air in the amount of 58 kg/s is introduced in the preheater 28 at a temperature of 42°C. It is heated up to 357°C by 64 kg/s of flue gas, that is taken from the outlet of the backpass 24 and that enters the preheater at a temperature of 385°C. The air is fed to the CFB 1 as fluidizing and secondary air, while the flue gas is further treated at a temperature of 150°C.

The temperature in the furnace and in the freeboard of the CFB is still at about 850°C. The solids/gas ratio at the outlet of the freeboard is again supposed to be 12, whereby the flue gas amount is the 84 kg/s. 20 kg/s of these flue gases are fed to the solids heater 13, in which the reactant is preheated to 225°C before injecting it in the boiler. The whole amount of the nearly 1000 kg/s of

solids separated (a cyclone efficiency of 99% is assumed) in cyclone 8, is returned via lines 6, 7 directly to the bed. A varying amount of calcined material, i.e. 24 kg/s is fed via line 10a to the FBHE and drained thereof at a temperature of 370°C.

This calcination mode is also performed for example during a time period of 12 hours, i.e. the night period where the price of power is low. A minimum energy that can be transferred is directly used for steam generation, while a maximum of alternate product has been produced.

To give an example of the heat surfacing and equipment configuration, the heat absorption profile within the backpass and the FBHE is the following:

- During power mode: In the backpass 3% of the heat are absorbed in the economizer, 16% in the evaporator and 7% in the superheater; in the FBHE 13% of the heat are absorbed in the economizer, 38% in the evaporator and 23% in the superheater.
- During calcination mode: In the backpass 9% of the heat are absorbed in the economizer, 58% in the evaporator and 22% in the superheater; in the FBHE 1% of the heat is absorbed in the economizer, 7% in the evaporator and 3% in the superheater.

Thus it is seen that the steam duty in the FBHE during calcination mode is only 12% of the total. Nevertheless the same heat exchanger that performs steam duty during the power cycle with the hot solids leaving the cyclone can also be used for cooling the drain material (lime+ash) leaving the furnace during calcination cycle.

The self-explanatory diagrams in Fig. 3 show the cyclic nature with each an operation curve. Curve A is the change of limestone feed rate to the CFB, curve B is the energy consumption in the CFB and curve C is the change of calcium to sulfur ratio in the CFB bed, all in function of time.

In the upper diagram it is to be seen that no limestone is fed during power generation mode. During calcination mode, high limestone feed rate is established with correspondingly high lime and alternate product discharge rate.

The middle diagram shows on the ordinate the ratio % to steam / % to steam + % to calcination. It is to be seen that in the power generation mode, since no calcination is performed, maximum energy that can be transferred is directly used for steam generation. During calcination mode, because the calcined product has high value, the objective is to minimize the amount of steam generated, and to maximize the lime throughput.

In the lower diagram it is to be seen that since very high amount of limestone relative to the sulfur content of fuel is fed during calcination mode, the calcium to sulfur ratio in the bed inventory and the drain reaches a peak value soon after the high limestone feed rate begins. At the end of the calcination mode, the sulfur associated with fuel consumes the free calcium oxide and, depending upon the split between fly ash and the bed, the effective free calcium to sulfur ratio drops. Due to the large inventory of the calcium, the minimum calcium to sulfur in the bed at the end of the power cycle is still considerably high ( $\text{Ca/S}=20$ ). This implies that overall during the whole operating cycle, very low sulfur emission level can be achieved. It is to be noted that during the power generation mode, no sulfur sorbent is introduced in the system, which increases the efficiency of the steam production.

The circulating fluidized bed can be operated at a low excess air level lowering the NO<sub>x</sub> emissions and increasing equipment capacity. For example when operating with 20% excess air the NO emission was 330 ppm and at 10% excess air the NO emission was 200 ppm. The carbon then contained in the fly ash escaped from the cyclone 8 and separated in the filter 37 and the carbon



added via discharged fluidized bed material can be supplied to a (downstream) clinkering process as a fuel.

During the calcination mode, the circulating fluidized bed can be operated with oxygen-enriched air. Pure oxygen can be mixed with air to increase the oxygen content of the combustion air. This decreases the amount of inert nitrogen fraction in the combustion flue gas. Consequently the amount of fuel that can be fired for a given total gas weight is increased and the amount of raw material that can be calcined can also be increased for one same size equipment.

In the embodiment of Fig. 2 the limestone is sized so as to be entrained and circulated in the boiler. The cyclone system is so designed as the circulating material having received an endothermic reaction that is not retained in the boiler furnace is separated in the cyclone system. Then part of those separated solids are fed via line 10 to said fluidized bed heat exchanger, in which it is cooled while steam is produced. Part of the cooled solids can be returned via line 11 to the boiler, while part of is drained off the FBHE via line 14 as the alternate product.

In this embodiment the amount of alternate product is constituted by the solids drained off via line 14 and the solids separated in the filter 37. Since the mean size of the ash and a certain part of lime that has been thermally milled within the boiler is typically smaller than 50 $\mu$ m it will escape the cyclone, while the char and the crushed lime/limestone, which is far greater in size will be retained in the cyclone.

If the power plant is run with low excess air, in the calcination mode the precalcined raw material produced in the power plant might contain some carbon coming from the fly ash. This carbon is also separated in the filter 37 with the lime and is added to the alternate product drained off in line 14. In this case in

the further treatment of the alternate product in a cement plant using a kiln, either the coal amount to the kiln has to be reduced appropriately or the amount of air through the kiln has to be augmented to burn the supplemental carbon.

Referring to Fig. 4, the equipment necessary for performing the cement production consists mainly of a raw mix preheater 50, a rotary kiln 51 and a clinker cooler 52.

The preheater 50 is a vertically arranged multistage suspension type preheater including a plurality of serially connected cyclone type gas/solids separators 53-56. The cyclones each have an inlet for gaseous medium and entrained cement raw mix, an outlet for separated gaseous medium and an outlet for separated solids. The preheater is equipped with an inlet 57 for cement raw mix. During the alternate entrainment and separation process in the cyclones, the raw mix is heated up by the gaseous medium supplied to the preheater tower. This air flows through the preheater in countercurrent relation to the flow of the raw mix, i.e. from cyclone 56 to cyclone 55, to cyclone 54 and finally to cyclone 53. Spent preheating gaseous medium leaves the uppermost cyclone 53 via an outlet to a known dedusting system. The preheated raw mix is supplied to the kiln 51 via a line 58.

This kiln has a feed end 59 and a discharge end 60 with a combustion zone near the discharge end. In the rotary kiln, the preheated and precalcined raw mix is burned into cement clinker. For the combustion in the kiln, a certain amount of fuel, i.e. coal is injected at the discharge end 60 via a burner together with primary air.

Via air intake lines 61, ambient air is introduced in the system by fans 62 to the clinker cooler and heated therein by cooling down the cement clinker. The heated air exits the clinker cooler in a first stream and is supplied to the kiln 51

as kiln combustion (secondary) air. The cement clinker is then forwarded from the discharge end 60 of the kiln into the cement cooler 52, which might be a moving grate. The cooled clinker is finally supplied via line 63 to a cement grinder, which is not shown.

The clinker production in this existing plant can be increased using at least the existing preheater tower 50 and the kiln 51, thus making better use of the cooler air and having the opportunity to give the kiln gases a separate treatment.

This increase is realized by feeding the calcined raw meal, consisting essentially of lime and combustion residues like ash, carbon and desulfurization residues taken from line 14 of the power plant, if need be completed by additives, via inlet 57 into the preheater 50. A second feature is to direct process air from the clinker cooler 52 in countercurrent flow to the direction of flow of the calcined raw meal. Thus air preheated in the clinker cooler is supplied to the preheater tower via tertiary air line 64 and via riser duct 65.

The kiln exhaust gases are 100% vented and can be used for steam production in a boiler.

Fig. 5 illustrates an embodiment in which the alternate product is cement clinker. In this process the lime-rich intermediate product is first cooled down in a cooler 70 that might be one or more compartments of the multi-compartment heat exchanger to about 400°C and then pulverized in a mill 71. It is then heated up to 1200-1400°C by addition of oxygen containing gas 72 and hydrocarbon 73 in a reactor 74 to make cement clinker. Cooling the cement clinker in a cooler 75 that might also be one or more compartments of the multi-compartment heat exchanger follows the process. It is to be noticed that in this cooler section there is heat extraction that might be used for steam production.

After the cooler 75 some solids are returned to the cooler inlet via a line 76 and mixed with the hot cement clinker at 1200 to 1400°C to lower the cooler inlet temperature down to about 800-900°C. The product is then forwarded into a storage tank 77. In the starting phase of the plant the cooler inlet temperature is lowered by feeding its inlet with some cold solids out of the storage tank 77. The cement clinker is then pulverized in a mill 78 with additives 79 such as gypsum to approximately below 100 microns to make cement.

In a preferred embodiment, the mills 71 and 78 may be the same piece of equipment.

The pulverization equipment used to pulverize the cement clinker is operated for grinding the clinker product during the power mode and to grind the cement raw material during the calcination mode.

The embodiment of Fig. 6 differs from that in Fig. 5 in that the lime-rich intermediate product has the right size to avoid further pulverization. The product out of the cyclone 8 is directly fed into the reactor 72 for cement making.

## List of Designations

- 1 circulating fluidized bed
- 2 limestone feed line
- 3 hydrocarbon feed line
- 4 secondary (overbed) air line to 1
- 5 fluidizing air supply
- 7 solids return line
- 6 solids return line bypassing 9
- 8 cyclone
- 9 fluidized bed heat exchanger
- 10 solids line to 9
- 11 solids line from 9 to 1
- 12 limestone crusher
- 13 solids heater, cyclone
- 14 draw off line
- 24 boiler backpass
- 27 fan
- 28 air heater
- 29 air supply to air heater
- 30 hot air discharge from air heater, air supply to 1
- 32 gas and fly ash line to boiler backpass 24
- 34, 134 economizer
- 35, 135 evaporator
- 36, 136 superheater
- 37 filter, electrostatic precipitator
- 38 gas exhaust line
- 39 steam drum
- 40 fan
- 41 stack

- 42 steam turbine island
- 50 preheater tower
- 51 kiln
- 52 clinker cooler
- 53-56 cyclone
- 57 inlet for cement raw mix
- 58 feed line to 51
- 59 kiln feed end
- 60 kiln discharge end
- 61 air intake line
- 62 fan
- 63 supply line to grinder
- 64 tertiary air line
- 65 riser duct
- 70 cooler
- 71 mill
- 72 oxygen containing gas
- 73 hydrocarbon
- 74 reactor
- 75 cooler
- 76 line
- 77 storage tank
- 78 mill
- 79 additives

### Claims

1. In a process of producing steam and an alternate product in a power plant, comprising feeding a reactant raw material, hydrocarbon and an oxygen-containing gas in a high temperature zone of a boiler, performing an endothermic reaction on the reactant in the boiler, discharging the product, producing steam in the boiler, further feeding the produced steam to a steam turbine island comprising a steam turbine being drivingly connected to a generator,  
the improvement comprising operating the power plant during high demands of steam or electricity in a steam cycle, whereas during low demands of steam or electrical power, operating the power plant in a mode maximizing the production of the alternate product by performing an endothermic reaction on the reactant with reduced steam production, the alternate product being stored after the endothermic reaction.
2. A process according to claim 1, in which the boiler is a circulating fluidized bed boiler and wherein the gas and the solids out of the fluidized bed enter a cyclone, the solids being separated therein being returned to the bed, whereby part of those separated solids are first cooled down in a heat exchanger, in which steam is produced, whereas the gas and the fly ash escaping the cyclone are passed through at least one heat exchanger and through a filter,  
the improvement comprising  
designing the cyclone system so as the circulating material having received an endothermic reaction and transformed to alternate product is

separated therein, and discharging the alternate product from at least one compartment of the multi-compartment heat exchanger.

3. A process according to claim 1, in which the boiler is a circulating fluidized bed boiler and wherein the gas and the solids out of the fluidized bed enter a cyclone, the solids being separated therein being returned to the bed, whereas the gas and the fly ash escaping the cyclone are passed through at least one heat exchanger and through a filter, the improvement comprising  
sizing the reactant so as to be retained in the furnace of the boiler, feeding at least part of the material having received an endothermic reaction and transformed to alternate product to a heat exchanger, in which it is cooled down while steam is produced and discharging the alternate product from at least one compartment of the multi-compartment heat exchanger.
4. A process according to claim 1, in which the boiler is a circulating fluidized bed boiler and wherein the gas and the solids out of the fluidized bed enter a cyclone, the solids being separated therein being returned to the bed, whereas the gas and the fly ash escaping the cyclone are passed through at least one heat exchanger and through a filter, the improvement comprising
  - sizing the reactant raw material so as part of it is retained in the furnace of the boiler, feeding at least part of the material having received an endothermic reaction to a heat exchanger, in which it is cooled down while steam is produced,
  - designing the cyclone system so as the lime-rich circulating material which have received an endothermic reaction, that is not retained in the boiler furnace is separated in the cyclone system, feeding part of those separated solids to said heat exchanger, in which it is cooled while steam is produced,



- and discharging the alternate product from at least one compartment of the multi-compartment heat exchanger.

5. A process according to claim 1, wherein at least one of the reactants is limestone and the alternate product is lime.
6. A process according to claim 1, wherein the reactants are limestone, clay, iron compounds and other additives constituting the composition of cement raw meal and the alternate product is a lime-rich intermediate having the correct composition to produce cement clinker.
7. A process according to claim 6, wherein the hot lime-rich intermediate product at around 800°C is cooled to approximately below 400°C, then pulverized to approximately below 100 microns.
8. A process according to claim 7, wherein the lime-rich intermediate product is heated to 1200 to 1400°C by addition of oxygen-containing gas and hydrocarbon in a reactor to make cement clinker, followed by cooling the cement clinker in at least one compartment of the multi-compartment heat exchanger.
9. A process according to claim 8, wherein the hot cement clinker at 1200 to 1400°C is mixed with cold solids to lower the temperature to about 800-900°C before cooling the mixture in at least one compartment of the multi-compartment heat exchanger.
10. A process according to claim 8 or 9, wherein the cement clinker is pulverized with additives such as gypsum to approximately below 100 microns to make cement.

11. A process according to claim 10, wherein the pulverization equipment used to pulverize the cement clinker is operated for grinding the clinker product during the power mode and to grind the cement raw material during the calcination mode.
12. A process according to claim 2, 3 or 4, wherein the circulating fluidized bed is operated at a low excess air level, the carbon then contained in the fly ash escaped from the cyclone and separated in the filter and the carbon added via discharged fluidized bed material being supplied to a (downstream) clinkering process as a fuel.
13. A process according to claim 5, 6 or 7, wherein during power mode the injection of sulfur sorbent is ceased.
14. A process according to claim 1, wherein the alternate material is cooled before storage/grinding).
15. A process according to claim 1, wherein during the calcination mode, the circulating fluidized bed is operated with oxygen-enriched air.
16. A process according to claim 2, 3 or 4, wherein the multi-compartment heat exchanger receiving the alternate product is a fluidized bed apparatus with immersed tubes

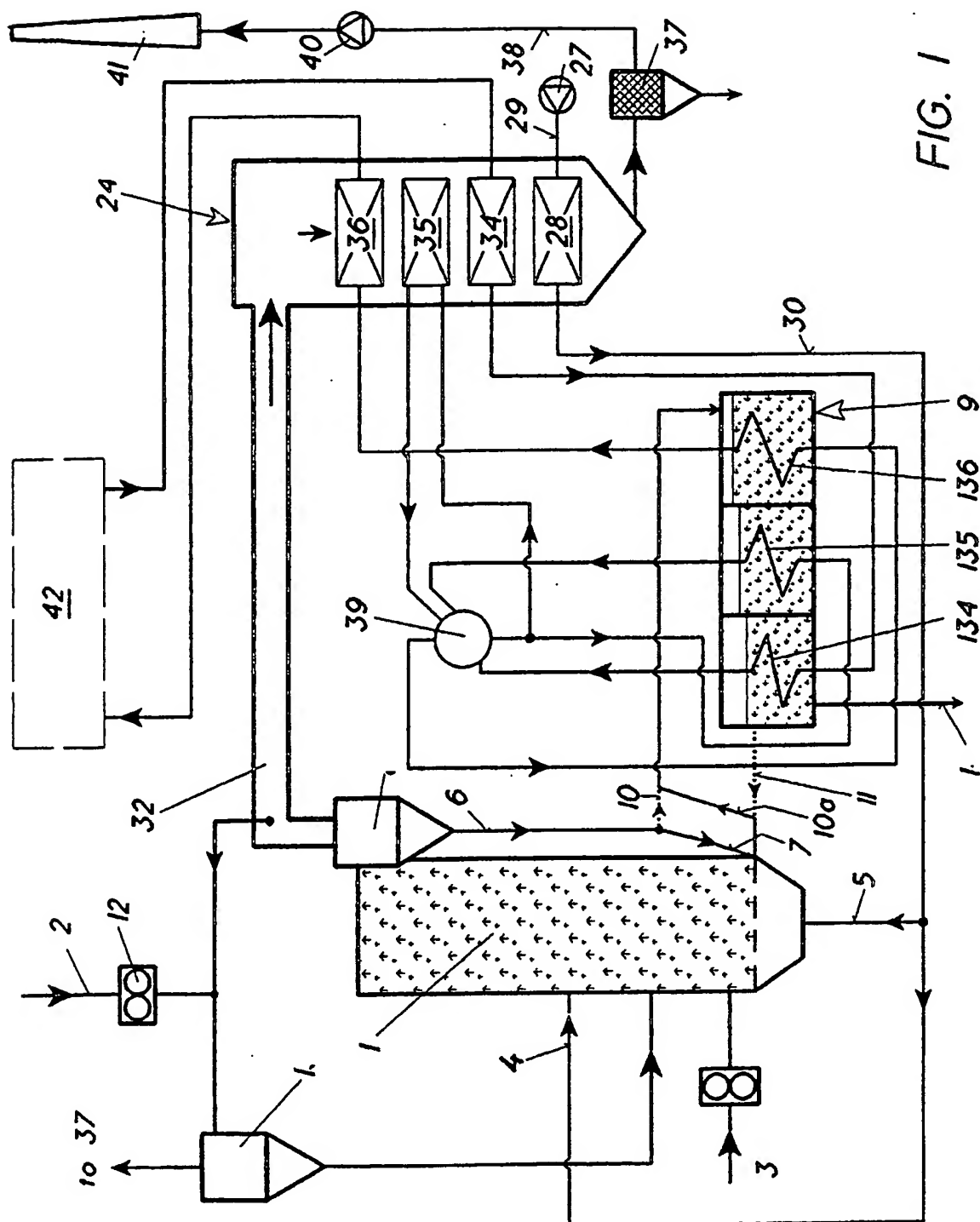
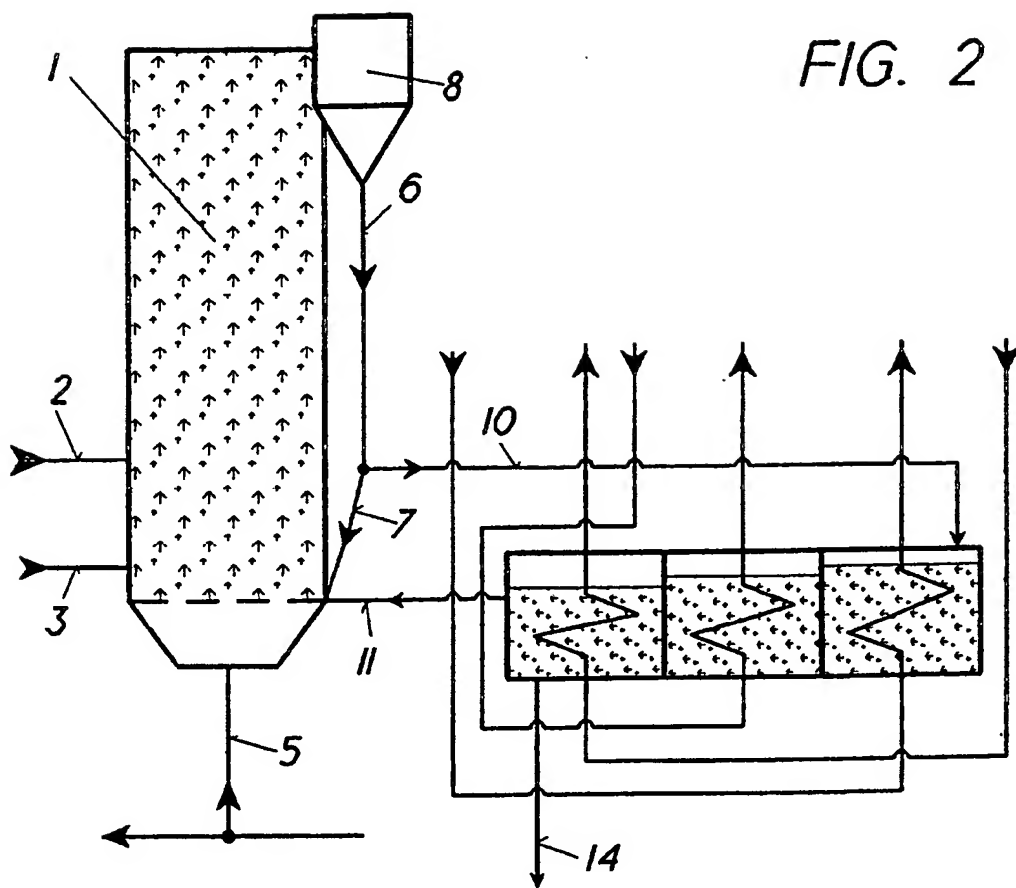


FIG. 2



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FIG. 3

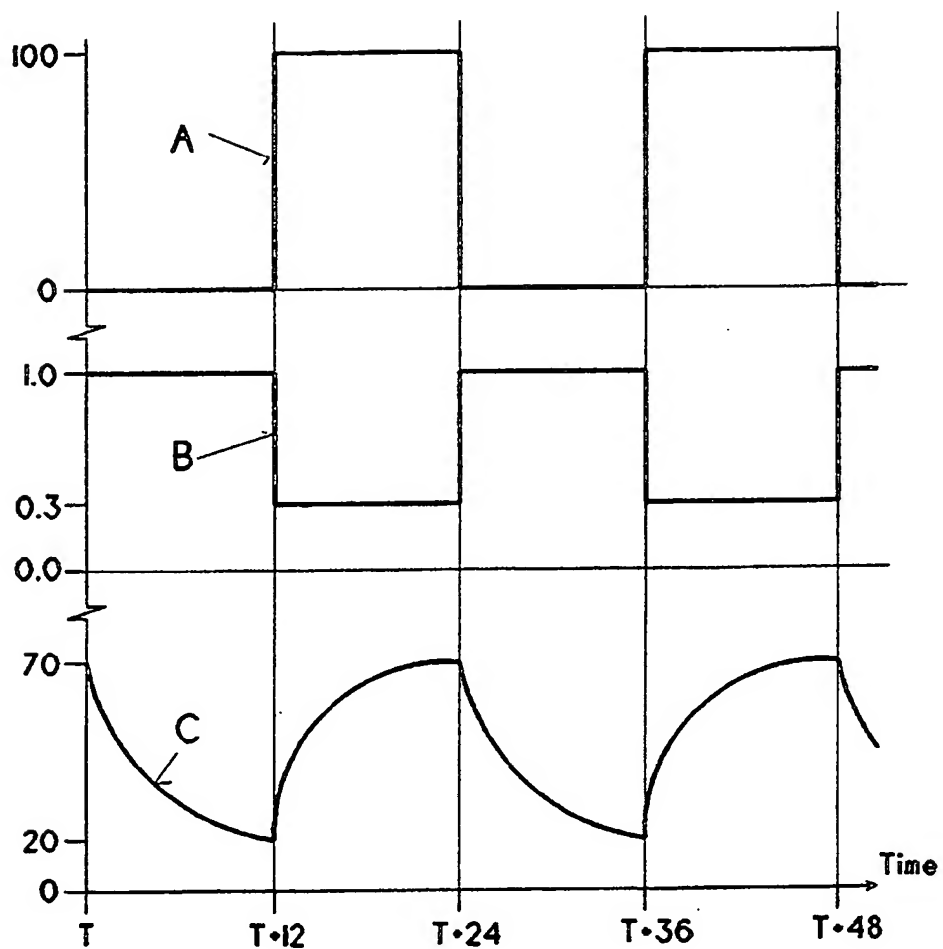
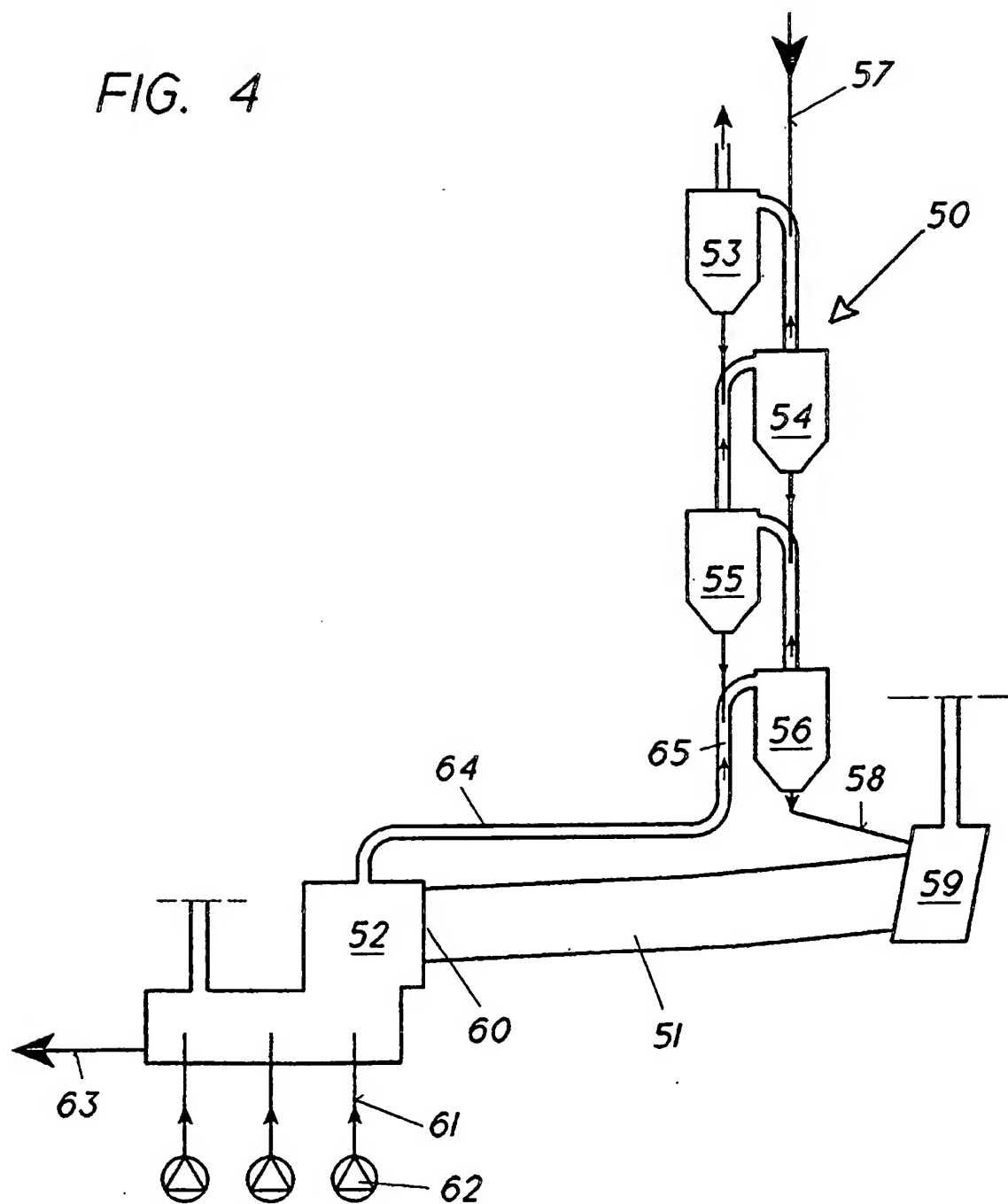


FIG. 4



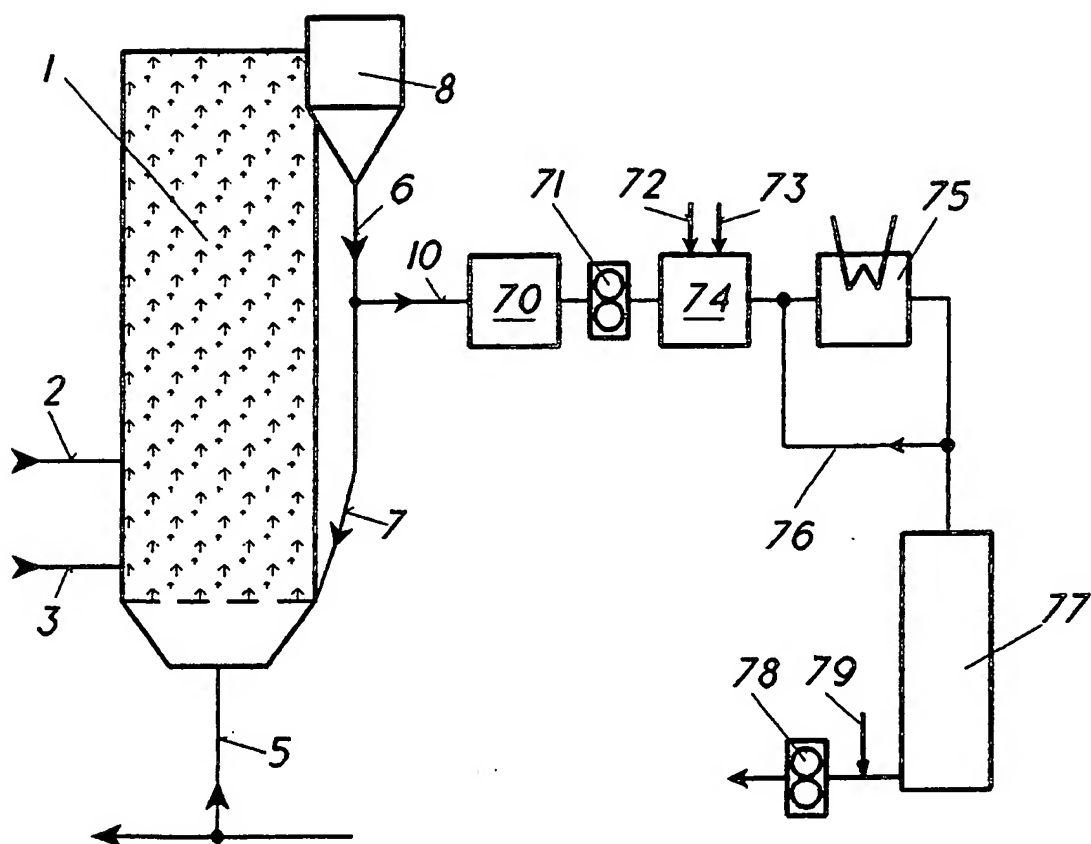


FIG. 5

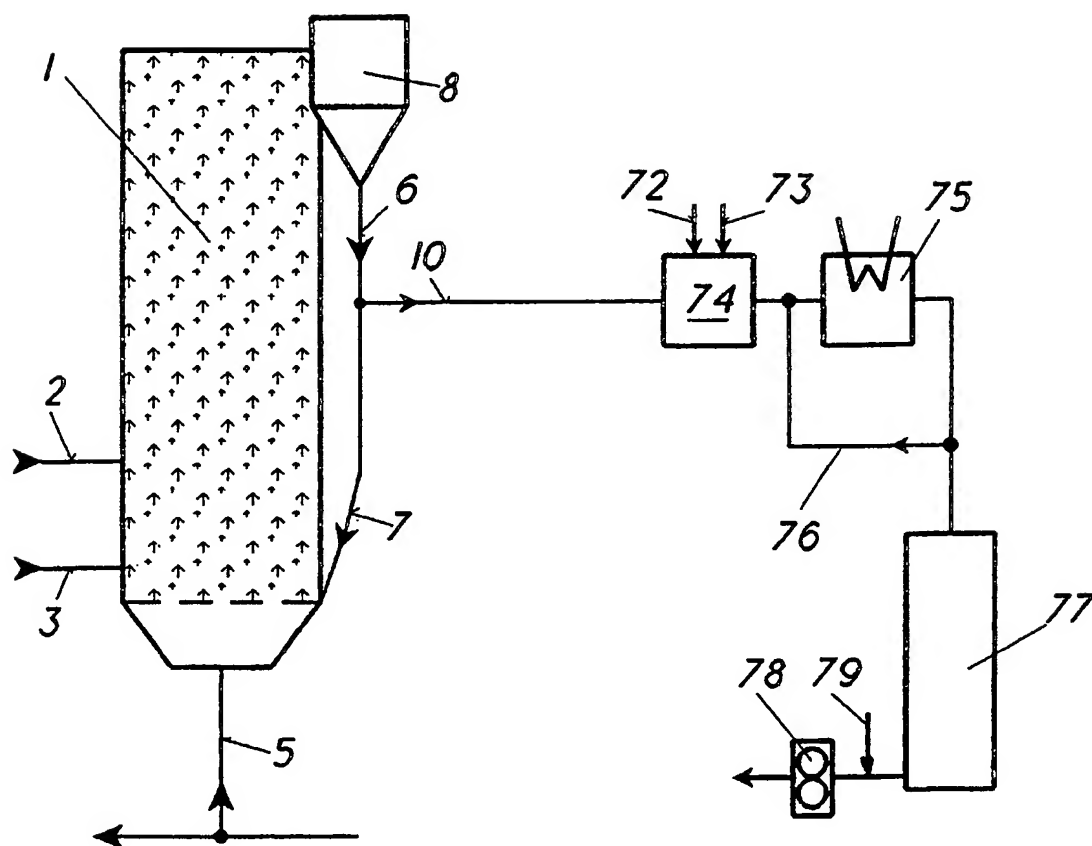


FIG. 6



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 01/00467

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CH 689830      A	15-12-1999	NONE	
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